

**COLOR IMAGE DISPLAY ACCURACY USING COMPARISON
OF COLORED OBJECTS TO DITHERED BACKGROUND**

5 This application claims priority from U.S. provisional application serial no. 60/193,725, filed March 31, 2000, U.S. utility application serial no. 09/631,312, filed August 3, 2000, and U.S. provisional application serial no. 60/246,890, filed November 1, 2000, the entire content of each being incorporated herein by reference.

TECHNICAL FIELD

10 The invention relates to color imaging and, more particularly, to presentation of color images on display devices.

BACKGROUND

5 The growth of the Internet has created sizable opportunities for online retailers. Most major retailers of consumer products have established commercial sites on the World Wide Web. At the same time, the availability of website presence has eliminated many of the marketing barriers previously experienced by smaller retailers. Virtually any retailer can now post product information for easy access by potential customers, and take orders for products in an automated fashion.

20 The product information may include a large number of images. The images enable web customers situated at client devices to view products before submitting an online purchase order. For some items, the user is permitted to click on a "thumbnail" image to view the item in a higher resolution format. For many retailers, however, the quality of the images can be a significant concern. Color accuracy, in particular, can be very important for retailers of products for which color matters.

25 In the case of clothing retailers, for example, an image of a sweater should match its actual color as closely as possible. Unfortunately, the color output characteristics of different display devices can differ significantly. A cathode ray tube (CRT) or flat panel display, video card, driver software, and operating system together
30 determine how RGB pixel values will be rendered and displayed, and vary significantly from system to system.

Consequently, an online customer may order what appears to be a burgundy sweater but instead receive a bright red sweater. Indeed, color inaccuracy has become a significant cause for return of merchandise purchased by online customers. In some cases, this problem can erase the advantages obtained by the retailer's commitment in to online merchandising, and undermine continued investment.

SUMMARY

The invention relates to improvement of color image display accuracy in a computer network having display devices with different color output characteristics. The invention, in one embodiment, makes use of a dithered gray background in estimating the gamma and gray balance of a display device. The term "gray," as used herein, generally refers to a color formed by combinations of two or more color channels of various gray levels, in contrast to colors formed by single color channels. To determine gamma or gray balance, a set of gray elements is displayed against a dithered gray background having a dither of approximately 25 to 40%. In some embodiments, the gray elements and the dithered gray background may be limited to the green color channel of the display device for an initial gamma determination.

Gamma can be estimated by selecting one of a set of green elements that appears to most closely match a dithered green background. For gray balance, the selected green element can be used to from a gray element that is displayed against a dithered gray background in conjunction with a set of red-blue shifted elements. Gray balance for the display device can be estimated by selecting one of the gray patches that appears to most closely match the dithered gray background. Together, gamma and gray balance can be used to characterize the colorimetric response of the display device.

In each case, the dithered background is selected to be in the range of approximately 25 to 40% gray level and, more preferably, approximately 33%. Dithered backgrounds in the range approaching approximately 33%, rather than 50%, more closely match the actual midpoint of black to gray transition for most display devices. In particular, the black to gray transition ordinarily is not linear for a typical CRT monitor. With a dither that produces a gray level in the range of approximately 25

Estimation of multiple, channel-specific blackpoints is based on the realization that some display devices, such as CRT monitors, exhibit very different blackpoints for different color channels, and can be difficult to characterize using only a single RGB blackpoint estimate. By estimating the blackpoint for each color channel (R, G, B) individually, a more accurate characterization of the overall colorimetric response of the display device can be obtained.

A more accurate colorimetric characterization, which may result from the use of an approximately 25 to 40% dithered background in the gamma and gray balance estimates, enables greater accuracy in a process for modification of color images that are delivered to and displayed on a particular display device. In this manner, the invention can provide improved color image display accuracy, particularly across a computer network. This can be achieved, for example, by obtaining the blackpoint, gamma, and gray balance to characterize a color response of a display device associated with a client device residing on a computer network.

The information can be used advantageously to modify color images delivered to the client over a computer network such as the World Wide Web. The invention, in various embodiments, may be applied to provide color imagery modifications that compensate for the color response of the individual display device associated with the client. The display device may take the form of a cathode ray tube monitor, flat panel display, or similar color image display device. The multi-channel blackpoint estimate and additional information can be obtained, for example, by guiding the client through a color profiling process that profiles the color response of the display device. Guidance may take the form of a series of instructional web pages that are delivered to the client via the computer network.

The web pages can be made interactive to enable collection of color characterization data from the client. The color characterization data can be used to estimate a variety of information concerning display device characteristics such as the

multi-channel blackpoint estimate, gamma, gray balance, and the like. Once the information has been collected, a color profile can be created for the client's display device, and thereafter used for modification of color images delivered to the client. The color profile can be incorporated in information that is transmitted by the client to an image server for modification of color images to be delivered to the client. The information transmitted by the client can be embodied in a web cookie or other information container.

A very accurate value for average gamma of RGB can be determined using a series of cascading steps. In some embodiments, for example, a gray patch selected for the coarse gamma measurement is used as the central patch for a range of gray patches used to measure a more finely tuned gamma. The fine gamma then can be used to form the central gray patch for gray balance determination. Advantageously, in some embodiments, the user can complete the color profiling process in as few as four clicks, while gray balance determinations can be completed in a single click.

A cookie, or alternative container, can provide a persistent representation of the color response characteristics of the client's display device. Each time the client accesses a web server and color images are identified in web page content, the cookie can be sent to the appropriate image server to improve the accuracy of the color image displayed on the client's display device. The cookie may contain a computed color profile for a display device or parameters useful in computing such a color profile and thereby rendering color modifications, or "corrections," to images provided to a client.

With improved color image accuracy, the images viewed by the client appear as intended. The system and method are capable of providing accurate characterization of a display device, while affording reliability and ease of use for the user. In a retail context, for example, the color of an item of interest more closely matches the actual color. As a result, items ordered by online customers are less likely to be returned based on color mismatch. Online retailers suffer from less returns, and online customers can shop with greater confidence that the items they order will arrive in the expected color.

In general, users viewing online images are able to see the colors intended by the original source without the need for significant adjustments to the display device.

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advantages of the present invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a system for improving color image display accuracy in a computer network;

FIG. 2 is a block diagram of a web-based environment incorporating a system as shown in FIG. 1;

FIG. 3 is a flow diagram illustrating a method for improving color image display accuracy in a computer network;

FIG. 4 is a flow diagram illustrating a color profiling process for a display device;

FIG. 5 is a flow diagram illustrating a multi-channel blackpoint determination in a color profiling process as shown in FIG. 4;

FIG. 6 is a diagram of a web page for analog adjustment of a color display prior to blackpoint determination;

FIG. 7 is a diagram of a web page for determination of blackpoint for a particular color channel;

FIG. 8 is a flow diagram illustrating gamma and gray balance determination in a color profiling process as shown in FIG. 4;

FIG. 9 illustrates a range of gray elements for use in determining a coarse gamma in a color profiling process as shown in FIG. 4;

FIG. 10 illustrates a range of gray elements for use in determining a fine gamma in a color profiling process as shown in FIG. 4;

FIG. 11 illustrates a range of gray elements for use in determining gray balance in a color profiling process as shown in FIG. 4;

FIG. 12 illustrates an example of a color image transmitted to a client in a system as shown in FIGS. 1 and 2;

FIG. 13 is block diagram illustrating transmission of color correction information in a system as shown in FIGS. 1 and 2; and

FIG. 14 is a block diagram illustrating an alternative architecture for a system for improving color image display accuracy in a computer network.

DETAILED DESCRIPTION

FIG. 1 is a block diagram of a system 10 for improving color image display accuracy across a computer network. The computer network may take the form of a local area network, wide area network, or global computer network such as the World Wide Web.

As shown in FIG. 1, system 10 may include a web server 12, a client 14, a color image server 16, and a color profile server 18. Web server 12 provides client 14 with access to one or more web pages incorporating graphic content such as color images. Some of the color images can be incorporated in the web pages stored at web server 12 while other color images can be stored at color image server 16. Web server 12 may store lower resolution color images, for example, as well as images that are less color-intensive. Higher resolution color images and more color-intensive images can be stored at color image server 16.

Web server 12, client 14, color image server 16, and color profile server 18 each execute instructions contained in program code stored on computer-readable media residing locally with the respective device or executed remotely. For client 14, for example, the program code may reside in random access memory (RAM) that is accessed and executed by the client computer. The program code can be loaded into the memory from another memory device, such as a fixed hard drive or removable media device associated with client 14. In particular, the program code can be initially carried on computer-readable media such as magnetic, optical, magneto-optic or other disk or tape media, or electronic media such as EEPROM. Alternatively, the program code can be loaded into the medium by transmission from a remote data archive, e.g., via a local area network, wide area network, or global network such as the Internet. A substantial portion of the code may be web page code that is transmitted to the respective device and executed by a server or browser application.

The web pages generated by web server 12 may comprise a variety of code, e.g., Hypertext Markup Language (HTML), Extensible Markup Language (XML), or the like, and may include image tags that point to specific color images stored at color image server 16 or elsewhere. When client 14 accesses a particular web page delivered by web server 12 and assembles the page content according to the HTML, client 14 may access color image server 16 to obtain any images tagged within the web page. Thus, the content of a web page assembled for client 14 may include objects obtained from different resources within the network occupied by system 10, such as web server 12 and color image server 16. In some embodiments, web server 12 and color image server 16 may be integrated with one another. In the example of FIG. 1, however, color image server 16 and web server 12 are separate entities. Web server 12 and color image server 16 each may interact with a database server and file server to obtain access to selected color images for delivery to client 14.

Client 14 may take the form of a variety of devices that permit a user to access resources on system 10 and display color images obtained from such resources. Examples of client 14 include desktop or portable computers operating in a Windows, Macintosh, Unix, or Linux environment, personal digital assistants (PDA's), based on the Palm, Windows CE, or similar operating system environments for small portable devices, Internet-equipped wireless telephones, interactive televisions with set-top boxes for Internet access, Internet kiosks available to the general public, and future Internet appliances that may emerge. Each client 14 preferably executes a graphical viewing application such as a web browser to access resources residing on other resources, such as web server 12 and color image server 16, attached to system 10. A web browser application permits the user associated with client 14 to readily view web pages generated by web server 12, and images served by color image server 16. Other user interface applications may be useful in accessing web server 12 provided the information is presented in a user-interactive format.

In some embodiments, color image server 16 may be configured to deliver color corrected video imagery, in addition to static images. Video, such as MPEG clips, streaming video, and the like may suffer from similar color accuracy issues if they are not compensated for the effects of the display device associated with an individual

client 14. Thus, some embodiments of the invention may be particularly useful for broadcast-like video content.

5 In each case, client 14 includes a display device, such as a cathode ray tube or flat panel display, for display of color images obtained from web server 12 and color image server 16. Other types of displays, as well as dynamic viewing media such as electronic paper, are contemplated. Communication between web server 12, client 14, and color image server 16 may take place using conventional network protocols such as TCP/IP. Although some of the client devices described above, such as PDA's and wireless telephones, presently incorporate relatively low quality color displays, it is
10 anticipated that such devices will benefit from higher quality color displays in the near future. Accordingly, system 10 will be readily applicable in enhancing the quality of color images displayed by PDA's, wireless telephones, and similar devices in the future.

As an illustration, web server 12 may deliver web pages associated with an online retailer such as a clothing merchandiser. In this example, the web pages
5 delivered by web server 12 may contain information concerning an array of items offered for sale by the retailer, as well as color images of the items for viewing by online customers. Some of the color images may constitute low resolution "thumbnail" images placed coincident with hypertext links to higher resolution images stored at color image server 16. Client 14 executes the code delivered by web server 12 within a
20 browser application to assemble a web page for display on a display device associated with the client.

When a user associated with client 14 clicks on one of the thumbnail images with a pointing device, such as mouse, trackball, pen, or the like, client 14 accesses color image server 16 to obtain the higher resolution color image designated by an
25 image tag embedded in the web page code. To permit display of the higher resolution color image with greater color accuracy, color image server 16 modifies the color image based on information obtained for client 14. In particular, color image server 16 obtains information characterizing the color response of a display device associated with client 14. The information can be uploaded to color image server 16, e.g., in the form of a
30 web cookie or other content container. Alternatively, the information can be transmitted, i.e., broadcasted, to a number of subscriber color image servers in system

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device, as indicated by reference numeral 40. For lower resolution images, such as so-called "thumbnails," the image tags may point to locations resident at subscriber server 12. When a user clicks on a thumbnail to access a higher resolution image, or when a higher resolution is embedded in the web page in the first instance, client 14 accesses and downloads a corresponding color image from a designated color image server 16, as indicated by reference numeral 42 in FIG. 3.

In the example of FIG. 3, client 14 queries whether a color profile cookie visible to the color image server has been generated for the particular client, as indicated by reference numeral 44. A cookie is visible, for example, if it corresponds to the domain of the color image server. Management of cookies will be described later in this description. The color profile cookie contains information characterizing the color response of the display device associated with client 14, and resides locally with the client. If a color profile cookie has been generated, client 14 uploads the cookie to color image server 16, as indicated by reference numeral 46. Color image server 16 retrieves the image requested by client 14 and modifies the image based on the contents of the cookie by applying a color correction, as indicated by reference numeral 48. The color correction modifies the image to compensate for variations in the color response characteristics of the display device associated with client 14. Color image server 16 then downloads the color corrected image to client 14, as indicated by reference numeral 50, and the process ends, as indicated by reference numeral 52. In the above manner, client 14 receives a color corrected image that is customized for the client's display device to provide more accurate color output.

If a color profile cookie has not been generated previously, client 14 downloads a default color image from color image server 16, as indicated by reference numeral 54, for presentation on the display device associated with the client. The image is a "default" image in the sense that it has not been color corrected or otherwise customized for the individual display devices associated with client 14. As a result, when displayed by client 14, the default image may exhibit significant color inaccuracy relative to the original color image. With the default image, however, client 14 may present a color profiling option, as indicated by reference numeral 56.

In particular, client 14 may download with the image an indication of whether color profiling and correction has been applied to the image. With the image, client 14 may display that indication along with a hypertext icon that may invite the user to carry out color profiling. The user may click on the profiling icon with a pointing device to access the color profiling process. In some embodiments, the profiling icon may indicate that profiling has already been performed and that the image has been color corrected, e.g., by displaying the icon in color. If profiling has not been performed previously, the icon may be displayed in black-and-white or some other indication can be provided. By clicking on the icon, the user can commence profiling, either in the first instance or as a profiling update.

If the option is not selected, as determined at reference numeral 58, the user simply views the default image and the process ends, as indicated by reference numeral 52. If the option is selected, however, client 14 accesses color profile server 18, e.g., via the hypertext link associated with the icon. Color profile server 18 guides the user associated with client 14 through a color profiling process, as indicated by reference numeral 60. The color profiling process produces information characterizing the color response exhibited by the display device associated with the particular client 14. Following completion of the color profiling process, client 14 generates a color profile cookie, as indicated by reference numeral 62. The color profile cookie contains the color characterization information. Client 14 then uploads the color profile cookie to color image server 16, as indicated by reference numeral 46, to obtain a color corrected image for improved color image accuracy. As will be explained, the cookie may need to be rewritten for the domain of the color image server 16.

Notably, as will be described, the color profiling process optionally requires no plug-ins, Java scripts, or other significant client-side processes. Instead, interaction between subscriber server 12, client 14, color image server 16, and color profile server 18 is driven by a series of web pages delivered to client 14. This approach yields significant convenience for the end user associated with client 14. At the same time, subscribers 22a-22n are not required to retain color information for individual users. Rather, the information can be uploaded to color image server 16, e.g., in the form of a cookie, whenever color images are requested by a client 14. Moreover, subscribers 22a-

22n can maintain their own color images at color image servers 16a-16n, and provide color correction by incorporating a color correction module capable of handling the color profile cookies uploaded by individual clients 14a-14n. Accordingly, there is no need for subscribers 22a-22n to post their web pages or images to a central web repository.

To carry out a color profiling process as described with reference to FIG. 3, client 14 interacts with color profile server 18. Color profile server 18 delivers a series of web pages to client 14. Each of the web pages is designed to guide the user through a given step in the color profiling process. One web page, for example, may include instructions and image content designed to extract from the user an estimate of the blackpoint of the display device. In one embodiment, the blackpoint estimate may be an estimate of multiple, channel-specific blackpoints. Other web pages may include instructions and content designed to extract coarse gamma, fine gamma, and gray balance information. In particular, each web page may include interactive media such as hypertext icons and the like that can be clicked upon by the user to transfer information from client 14 to color profile server 18.

Upon collecting the necessary information, color profile server 18 creates the cookie and delivers it to client 14 for local storage and future use. In some embodiments, two cookies can be provided to client 14. A first cookie may correspond to a domain name associated with color profile server 18, and be used for future interactive between the particular client 14a-14n and the color profile server. The first cookie can be referred to as the "profiler cookie." A second cookie may correspond to a domain name associated with the particular color image server 16a-16n (corresponding to a particular subscriber such as a retailer) from which the color image is to be downloaded. In other words, the second cookie may correspond to the color image server 168a-168n at which the color profiling process was initiated. In this manner, future images delivered by that color image server 16a-16n will be modified based on the contents of the cookie associated with the pertinent domain. The second cookie can be referred to as the "subscriber cookie."

The profiler cookie can be used to produce additional subscriber cookies for use with color image servers 16a-16n associated with other domains. Specifically, when a

user situated at a client 14a-14n accesses a color image server 16a-16n from which the user has not previously downloaded color corrected images, the user can click on the color profiling option and be directed to color profile server 18. Upon interaction with color profile server 18, client 14 simply uploads the profiler cookie instead of repeating the color profiling process. Information concerning the domain associated with the new color image server 16a-16n can be incorporated in the profiler cookie.

In response to receipt of the profiler cookie, color profile server 18 delivers a web page advising the user associated with client 14a-14n of the intent to send the cookie contents to the domain indicated in the cookie, and may request user approval for, among other reasons, privacy concerns. Upon approval by the users, color profile server 18 transmits the cookie contents to the color image server 16a-16n designated by the domain in the profiler cookie. In response, the color image server 16a-16n creates a subscriber cookie for its own domain, and writes the cookie to client 14a-14n for future use. Thereafter, client 14 uploads the appropriate subscriber cookie to the pertinent color image server 16a-16n when requesting color corrected images for the pertinent subscriber 22a-22n, and can bypass interaction with color profile server 18.

The reliance on first and second cookies, one for color profile server 18 and the other for a particular subscriber server 12a-12n or color image server 16a-16n, is driven in part by existing web design considerations. In particular, cookies stored on a client's browser typically are marked by the domain of the server that generates them, and are not generally visible to other domains. Thus, cookies created by color profile server 18 are not generally visible to color image servers 16a-16n, and vice versa. Cookie visibility can be further restricted by marking the cookie with a path within a server's domain. This sort of cookie will then not be visible on requests to pages outside the path, even if to the same domain. Further, a browser routinely sends all visible cookies on each request to a server. This includes not only the initial request for an HTML page, but also the requests for images to be embedded in the page. Because an image can come from a different server than the HTML page, however, the cookies sent for the HTML page can differ from those sent for the image.

In light of the above considerations, color profile server 18 acts as an intermediary not only for administration of the color profiling process, but for

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information remains a viable option that may be acceptable to some subscribers 22a-22n, and highly convenient for end users.

The following is a description of some of the details that may be associated with passing information between subscriber servers 12a-12n, clients 14a-14n, color image servers 16a-16n, and color profile server 18 according to an indirect cookie transfer approach. This approach is indirect in the sense that the user intervenes and enters approval before the profiler cookie contents are transferred from color profile server 18 to a respective color image server 16a-16n. In delivering web pages to clients 14a-14n, subscriber servers 12a-12n pass the URL's for correctable images stored on associated color image servers 16a-16n. In addition, subscriber servers 12a-12n preferably incorporate color profiling icons near the images. The URL's for the color profiling icons point to the pertinent color image server 16a-16n, while the hypertext link associated with the icon points to color profile server 18.

To accomplish passing of color correction information back to color image server 16a-16n, the URL of the page viewed by the user is passed to color profile server 18 when the hypertext link associated with the icon is followed by a client 14a-14n. This step of passing the URL can be accomplished either by including the URL as a parameter on the target URL, or by POSTing the information from a form that wraps the icon, i.e., with the URL stored in a hidden entry field. In the latter case, the icon serves as a button, which may require some minimal client-side scripting. In addition, as will be described, the name of the subscriber 22a-22n and the URL of a completion page to be served by the color image server 16a-16n after the color profiling process is complete may be included in the request to color profile server 18. Subscribers 22a-22n can be provided with a server-side scripting function that inserts the icon code with the appropriate URLs.

For the color profiling process, color profile server 18 serves a number of web pages that can be invoked by execution of a web page provided by subscriber server 12a-12n. In this case, the "return URL" is passed forward to each page in the sequence. The return URL can be passed as a parameter in the target URL, or by using hidden fields in forms. In some cases, the return URL can be stored as a server variable. As mentioned above, color profile server 18 handles two scenarios: (1) full color profiling

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The client and subscriber IDs are passed via URL parameters to color profile server 18 whenever a color image server 16a-16n has no color correction information for a particular client 14a-14n. The subscriber ID is passed back with the color correction information from color profile server 18 to the color image server 16a-16n when the color profile server determines the appropriate information for the client, based on the contents of a profiler cookie or the results of running the color profiling process. Once color image server 16a-16n receives this information and writes it as a subscriber cookie to the client's browser, the subscriber ID is no longer needed.

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green, and blue (R, G, and B) color channels of the display device, (2) average gamma for R, G, and B, and (3) differences in gamma for R, G, and B. Due to the wide range of differences in display device properties, determination (2) above can be subdivided into determination of (2a) a coarse gamma estimate, and (2b) a fine gamma estimate.

5 This process is described in greater detail below with reference to FIGS. 4-11.

As indicated by reference numeral 64 in FIG. 4, the color profiling process first involves determination of an estimated blackpoint for each of the color channels of the color display device, e.g., R, G, B. After determining the blackpoints, which may be merely an estimate, the color profiling process involves determination of the gamma exhibited by the display device. In particular, the process may involve determination of a coarse gamma, as indicated by reference numeral 66, followed by determination of a fine gamma, as indicated by reference numeral 68. Determination of the fine gamma may rely in part on the coarse gamma. In other words, the coarse gamma can be used as an initial estimate and starting point for convergence toward a more finely tuned gamma.

After determining the fine gamma, the process may involve determination of the gray balance exhibited by the display device, as indicated by reference numeral 70 of FIG. 4. Gray balance provides an indication of the amount of color shift of a neutral gray toward one or more of the color channels used by the display device, e.g., red, green, and blue. The gray balance determination may rely in part on the gamma determined previously in the color profiling process and, in a particular embodiment, the fine gamma. Next, the color profiling process involves generation of a color profile, as indicated by reference numeral 72. The color profile contains information that characterizes the color response of the display device based on the determinations indicated by reference numerals 64, 66, 68, 70, i.e., blackpoints, gamma, and gray balance. The color profile then can be loaded into a cookie, or other content container, and stored locally with client 14 for uploading to any of color image servers 16a-16n when needed, as indicated by reference numeral 74.

The estimated blackpoint parameters define the dynamic range of the display device. Because the maximum RGB value always defines white, the blackpoint defines the black end point, and therefore defines the domain of values for each of the R, G, and

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can better engage the pattern recognition capabilities of the human eye and result in heightened sensitivity to gray scale differences. When the human eye is called upon to perform pattern recognition, its sensitivity to color gradations between a given pattern and a surrounding area increase. The complex shape presents a longer boundary relative to simple shapes, and promotes an increased perimeter for contrast. Elements with complex shapes may be used in the blackpoint, coarse gamma, and fine gamma determinations to characterize the monitor.

As an alternative to rows, the elements can be arranged in columns placed side-by-side across the web page. As a further alternative, each row or column may contain, instead of several elements, only one or a small number of elements. A larger number of elements in each given row may aid the user in resolving differences between elements in adjacent rows.

The web page may instruct the user to set the brightness and contrast of the display device to maximum, as indicated by reference numeral 78. The rows (or columns) of elements may be arranged in a series. The elements in each row preferably exhibit the same darkness or lightness. However, the elements in each row in the series differ in relative darkness or lightness relative to the elements in other adjacent rows. For example, the darkest row of elements could be situated at the bottom, with rows containing elements with progressively lighter shades being situated above in ascending order. As indicated by reference numeral 80, the web page instructs the user to reduce the brightness until the darkest row of elements is barely visible. At this point, the user may select "next" or some similar hypertext icon and proceed to the next step in the color profiling process, e.g., blackpoint determination for each of the red, blue, and green channels on an individual basis.

FIG. 6 illustrates an example web page 122 for use in display device adjustment in a color profiling process as shown in FIG. 5. Client 14 displays rows 124 of dark elements with the elements of each row having the same gray level value, but elements in adjacent rows having different gray level. As an example, rows 124 of dark elements (shown as numerals in the example of FIG. 7) may be presented to the user with the following gray level values: 8, 16, 24, and 32. In other words, the rows of "zeros," "ones," "twos," and "threes" may have gray levels of 8, 16, 24, and 32,

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Upon selection of the row that is barely visible for the red channel, e.g., upon clicking on any element in the row, color profile server 18 automatically serves the user a substantially identical web page containing rows of green elements set against a black background for purposes of determining the green channel blackpoint. In this manner, the user selects a visible row or element that most closely appears to match, or blend with, the black background. Following selection of a row of green elements that is barely visible, color profile server 18 serves the user a substantially identical web page for blue channel blackpoint determination and the user makes a similar selection. Thus, color profile server 18 automatically serves successive web pages governing blackpoint determination for each color channel following selection of a row for a preceding channel. Alternatively, the web pages may prompt the user to click on a “next” icon or similar device. Serving successive web pages automatically following selection of an element may be desirable, of course, to reduce the overall number of clicks involved in the process.

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$$B = \begin{cases} \left[\frac{(d_b - k_{o,b})}{(1.0 - k_{o,b})} \right]^{\gamma_b} & \left[\frac{(d_b - k_{o,b})}{(1.0 - k_{o,b})} \right] \geq 0 \\ 0 & \left[\frac{(d_b - k_{o,b})}{(1.0 - k_{o,b})} \right] < 0 \end{cases}$$

The variables d_r , d_g , and d_b are the digital input values normalized to 1.0. The parameters $k_{o,r}$, $k_{o,g}$, and $k_{o,b}$, are the blackpoint offsets and the parameters γ_r , γ_g , and γ_b are the gammas for the red, green, blue channels.

The values of parameters $k_{o,r}$, $k_{o,g}$, and $k_{o,b}$, are determined as follows: Assume that (regardless of the properties of a particular monitor) for the red channel there exists a minimal visible set of values for XYZ that can be detected by the human eye, designated as the vector $(X_{t,r}, Y_{t,r}, Z_{t,r})$. This vector will have a unique corresponding value for R in the expression above, designated as R_t . For a particular monitor with specific values of γ_r and $k_{o,r}$ there will be a unique device value associated with R_t which is designated by $d_{t,r}$:

$$R_t = \begin{cases} \left[\frac{(d_{t,r} - k_{o,r})}{(1.0 - k_{o,r})} \right]^{\gamma_r} & \left[\frac{(d_{t,r} - k_{o,r})}{(1.0 - k_{o,r})} \right] \geq 0 \\ 0 & \left[\frac{(d_{t,r} - k_{o,r})}{(1.0 - k_{o,r})} \right] < 0 \end{cases}$$

This device value $d_{t,r}$ is determined by the user during the color profiling procedure as described, i.e., by selecting the darkest barely visible row of elements in the blackpoint determination web page for red. The value of R_t is empirically determined. For example, for a calibrated display system in a dark room with $k_{o,r} = 0.0$ and $\gamma_r = 2.2$, a red patch may be visible for $d_{t,r} = 8/255$ gray levels which implies $R_t = (8/255)^{2.2}$.

The exact value of $k_{o,r}$ can be calculated by solving two simultaneous equations, namely the equation above for R_t and the equation for $R_{.33}$ which will be described below. Alternatively, a reasonable estimate can be made for $k_{o,r}$ by assuming a gamma of 2.2. If this assumption is made, the value of $k_{o,r}$ can be estimated as:

FIG. 8 is a flow diagram illustrating gamma and gray balance determination in a color profiling process as shown in FIG. 5. For determination of coarse gamma, one of the web pages served by color profile server 18 displays a range of green elements, e.g., patches, against a dithered green background, as indicated by reference numeral 100. The coarse gamma determination web page can be served immediately and automatically following selection of a row of elements in the last blackpoint determination web page, or in response to selection of a “next” icon or similar device.

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range of green patches displayed against a green dithered background is shown in FIG. 9 and indicated by reference numeral 132. This range of green patches and the green dithered background can be displayed in a web page served by color profile server 18. Based on the selected green patch, which again may be selected by clicking on it with a pointing device, color profile server 18 computes a coarse gamma, as indicated by reference numeral 104 in FIG. 8. The coarse gamma determined in this step can be used as an estimate for the average gamma of R, G, and B via selection of a green patch from the set of green patches against the dithered green background. The dithered green background may be set at approximately 25% to 50%. Dithered backgrounds approaching approximately 33% may more closely match the actual midpoint of black to green transition for the display device, and may be preferred for typical display devices.

By alternating black and green at an appropriate frequency, a 25%, 33%, or 50% green background can be produced. For a CRT, turning on or off all of the pixels in a given horizontal line should produce more predictable output from display device to display device than modulating individual pixels to form vertical lines, due to the video bandwidth of the device. For flat panel devices, this is less of an issue. To accommodate clients using both CRT's and flat panel devices, however, generation of the dithered background by use of alternating horizontal lines is preferred.

The center patch in the range 132 of patches can be based on an average gamma of 2.0, since most monitors range from 1.6 to 2.5. The other green patches that surround the center patch may proceed in a sequence with relatively large steps, e.g., 8 gray levels apart from one another. Coarse gamma can be estimated using the equation:

$$G_{.33} = .333 = \left[(d_{.33,g} - k_{o,g}) / (1.0 - k_{o,g}) \right]^{\gamma_g}$$

where $d_{.33,g}$ is the gray level value (normalized to 1.0) of the selected patch that appears to most closely blend in with the background, $k_{o,g}$ is the previously determined blackpoint, $G_{.33}$ is the relative intensity of the green channel (equal to 1/3), and γ_g is the green gamma. As an alternative to actually computing the coarse gamma, the green

level value of the selected patch simply is carried forward for use in the fine gamma process. In this case, the value can eventually be discarded.

After the coarse gamma estimate is obtained, fine gamma is estimated. Fine gamma is a refined or "fine-tuned" estimate for the average gamma of R, G, and B.

5 Fine gamma can be determined by selection of another green patch from a set of green patches presented against a dithered green background with an approximately 25% to 40% and, preferably, 33%, dither. In this case, the center patch may be identical to the green patch selected by the user for determination of coarse gamma. Thus, the coarse gamma step "informs" the fine gamma step. In effect, the selected coarse gamma patch

10 may serve as a starting point for the fine gamma determination. Specifically, the green patch selected in the coarse gamma determination can be used as the central patch for the fine gamma determination.

A range of patches for determining fine gamma is illustrated in FIG. 10 and designated by reference numeral 134. The patches in this range are in a sequence with

15 smaller steps centered about the center green patch selected in the coarse gamma process. For example, the patches may be set at 4 green levels apart, in contrast to the 8 green levels used as the difference for the coarse gamma determination. In this manner, a narrower range is used to "fine-tune" the coarse gamma estimate, with the center of the range having been "learned" from the coarse gamma estimate.

20 As indicated by reference numeral 106, a web page served by color profile server 18 displays the selected green patch from the coarse gamma estimate among a narrower range of green patches. The user then is instructed to select the green patch that most closely blends with the same dithered green background as used for coarse gamma, as indicated by reference numeral 108. Based on the selected patch, color

25 profile server 18 computes a single fine RGB gamma, as indicated by reference numeral 110. Thus, the fine gamma is the overall gamma estimated for the RGB channels. Alternatively, as mentioned above, the RGB value of the selected patch can simply be stored for use by color image server 16a-16b in computing fine gamma and rendering color corrections. In any event, a refined estimate for gamma can be computed

30 according to the equation:

$$G_{.33} = .333 = \left[(d_{.33,g} - k_{o,g}) / (1.0 - k_{o,g}) \right]^{\gamma_g}$$

where $d_{.33,g}$ is the green level value (normalized to 1.0) of the selected patch that blends in with the background, $k_{o,g}$ is the previously determined blackpoint, $G_{.33}$ is the relative intensity of the green channel (equal to 1/3), and γ_g is the green gamma.

To determine gray balance, color profile server 18 serves a web page that displays a plurality of RGB patches. The RGB patches can be generated with the same value of green selected in the previous fine gamma step in conjunction with values of red and blue that are substantially equal to or systematically shifted from the previously selected value of green. The RGB patches can be displayed against a gray background which is dithered in the same manner as the green dithered background of the previous step (fine gamma), as indicated by reference numeral 112. Again, this step “learns” from the previous one, and forms part of a cascading series of color profiling steps (coarse gamma, fine gamma, and gray balance) that help narrow the search for the correct gamma. As indicated by reference numeral 114, the user is then instructed to select the gray patch that appears to most closely blend with the dithered background. Based on the selected gray patch, individual RGB gammas are computed, as indicated by reference numeral 116. Notably, the overall gray balance determination can be made with a single click of the user’s pointing device.

Thus, in this gray balance process, the green intensity value selected in the fine gamma process is used to generate the gray patches that exhibit +/- (plus/minus) differences or “shifts” in red and blue about the value of the central gray patch derived from the gamma estimate. For example, the value of green selected in the fine gamma process can be displayed in the center of the range in conjunction with substantially identical values of red and blue. The gammas for red and blue are then fine tuned by the gray balance determination, which helps identify red-blue imbalance in the display device. Thus, the green gamma is “locked in” in the gray balance step, while the red and blue imbalance is determined. In other words, every patch in the gray balance array carries the same green value, but is modulated by different gradations of red and blue.

This step eliminates one axis of variation, green, but permits identification of any

imbalance between red and green or blue and green. This limits the range of choices to a more finely-tuned area, and aids the user in making a more accurate selection.

The range of patches for the gray balance determination may be a two-dimensional array of patches with red-blue-shifted patches arranged around the central gray patch formed according to the gamma estimate from the fine gamma process. In other embodiments, the red channel could be used to determine the initial RGB gamma estimate, followed by a gray balance determination that resolves imbalance between green and red or blue and red.

FIG. 11 illustrates an example of a two-dimensional range 136 of gray patches arranged in a five-by-five matrix for use in the gray balance determination. Each patch represents a shift away from the central gray patch along either the blue axis, the red axis, or a combination of both, but preferably does not represent any further green shift. The user selects the patch that appears to most closely blend with the dithered gray background, which may be a 33% dithered background. The central patch can optionally be highlighted to indicate it is the preferred default choice.

The number of patches and the exact values of RGB for each patch can be quite flexible. For example, in the case of the image in FIG. 11, all patches can be selected to have identical values of L^* as indicated by the estimated profile for the display based on phosphors, average gamma, and blackpoint. Patches adjacent to the center may differ by all permutations of $\pm 3 \Delta E$ for a^* and for b^* as estimated from a Matrix TRC (tone reproduction curve) profile constructed from the above parameters.

Patches around the outer perimeter of the grid array may differ from the center by $\pm 6 \Delta E$ in R and B. Alternatively, for simplicity, one can elect to vary R and B only by \pm a fixed amount such as ± 5 gray levels and ± 10 gray levels. Preferably, all patches are relatively small deviations from the central patch in all directions of color space of approximately constant L^* . This test will help determine in a sensitive manner whether there exists a significant difference in the gammas of R, G, and B, and thereby expose significant gray imbalance between R and B.

The two-dimensional format of the patches shown in FIG. 11 may aid the user's selection of the correct patch. A gray patch based on the initial gamma estimate from the previous step in the color profiling process, i.e., fine gamma, is placed at the center

in this embodiment. Adjacent patches differ in gray level as the array extends outward such that the outer periphery of the array contains patches that are two gradations removed from the central patch. The array produces a visual “funnel” effect that, from experience, tends to direct the user toward the central patch as the starting point for matching with the background. The differences between patches in the two-dimensional array are more clear and dramatic than in a one-dimensional strip of patches. As the array extends outward, the shift becomes greater. Thus, the gradations are well pronounced and aid the user in picking the appropriate patch which, in many cases, will be the central patch.

If the user selects the central patch, a single gamma value is used for the R, G, and B channels. If one of the other patches are selected, three separate gammas are calculated based on the equations:

$$R_{.33} = .333 = [(d_{.33,r} - k_{o,r}) / (1.0 - k_{o,r})]^{\gamma_r}$$

$$B_{.33} = .333 = [(d_{.33,b} - k_{o,b}) / (1.0 - k_{o,b})]^{\gamma_b}$$

where the subscripts for γ and $d_{.33}$ indicate unique values for the R and B channels. The values for $d_{.33}$ for each channel are given by the values of RGB of the particular patch selected in this gray balance step. These equations are combined with a set of phosphor values to generate accurate profiles for the client’s display device, using equations well known in the art, and referred to as Matrix TRC formalism in the International Color Consortium (ICC) specification. Again, calculations can be performed by color profile server 18 or by a color correction module associated with color image servers 16a-16n.

The process of selecting patches in the coarse gamma, fine gamma, and gray balance determination steps is advantageous because, in preferred embodiments, it requires no applications, applets, or other client-side scripts to be loaded at the client side. Rather, the user may simply select one of the patches displayed in a web page. In other embodiments, however, if applications, applets, or client-side scripts are used, it is conceivable that smooth slider bars, +/- arrows, and the like could be used to adjust the color of a single patch in real-time for comparison to the dithered background. In this

manner, the user has the ability to precisely match a single patch to the background, rather than select from a finite set of patches the one that most closely matches. This technique of real-time adjustment also may be useful for non-networked approaches to color calibration and characterization. In this case, for blackpoints, gamma, and/or gray balance, the patch or element selected by the user may be a single adjustable patch in a condition in which the slider or other adjustment medium has adjusted its color to a level that is visually acceptable to the user, i.e., to a point at which the patch appears to match the dithered background.

Based on the blackpoint, coarse gamma, fine gamma, and gray balance processes, a color profile for the display device is generated, as indicated by reference numeral 118. Upon generation of the color profile, a color profiler cookie is created, as indicated by reference numeral 120. Information representative of the color profile is added to the color profiler cookie for future use. In particular, the information can be used to create a subscriber cookie for future interaction between the particular client 14a-14n and the particular subscriber 22a-22n and color image server 16a-16n. Although the color profile is especially useful for characterizing display devices in a network, it also may be useful in a non-networked application. In particular, the color profiling process described herein may find ready use in the calibration and characterization of an individual display device for correction of content generated or obtained locally with the device, rather than across a network.

Advantageously, there is no need for the client 14a-14n to provide information regarding the configuration of its display device. Very satisfactory results can occur using an average set of phosphor values based on published standards such as sRGB, Apple Macintosh RGB, and the like. If desired, further steps can be added, particularly in order to address the issue of phosphor values and white point. The color profiling process simply results in generation of a cookie that serves as a container and vehicle for passing information characterizing the color response of the display device associated with client 14a-14n to color image server 16a-16n. Alternatively, the chromaticity information and white point can in some cases be obtained from the display utilizing communication protocols such as VESA and/or from the operating system of the computer. The usefulness of this invention will continue because, with

current technology, the RGB blackpoints and gammas are difficult to maintain perfectly at the hardware level even with expensive electronic circuitry.

Ordinarily, all cookies visible to a particular domain are attached to each request from a browser application executed by a client 14a-14n. For this reason, a typical browser limits each domain to a maximum of twenty cookies. To avoid consuming the allotment of cookies for a particular subscriber 22a-22n, all of the color correction information for a particular client 14a-14n preferably is packed into a single profiler cookie and a single subscriber cookie. For example, a number of items can be packed into the value string of the subscriber cookie or the profiler cookie, as the case may be. In particular, each cookie should include the gamma values for R, G, and B. Each gamma value may be a value between 1.0 and about 3.0. In addition, the cookie may include the chromaticity values for black and white, e.g., expressed as a value between 0 and +1000.0.

An exemplary cookie may have the following items packed into its value string, each demarcated by a separator:

- (1) Cookie format version code – a numeric code, e.g., 1 to 3 bytes, plus separator.
- (2) Cookie installation date – the usual cookie-style timestamp (milliseconds after midnight of Jan. 1, 1970, GMT), e.g., 12 to 13 bytes, plus separator.
- (3) Unique profiler ID assigned to this color information when it is generated by the color correction sequence; a long integer, e.g., 4 bytes, plus separator (but possibly longer).
- (4) Gamma and blackpoint values for R, G, B – each a text representation of a floating-point value between 1.0 and about 3.0, retaining 4 decimal digits. The decimal point could be implied. Thus, the gamma values may take up 5 or 6 bytes plus a separator each, or three times that overall. Alternatively, the selected tint values chosen for R, G, and B can be indicated, enabling the gamma and blackpoint values to be calculated at a later time by a server upon upload of the cookie.
- (5) Chromaticity for Black and White – each a text representation of a floating-point value between 0 and +1000.0, retaining 4 significant digits. Thus, this may take up 6 or 7 bytes plus a separator each, or two times that overall.

(6) Number of bits per color – two decimal digits: two bytes plus separator.

(7) Display Device ID code – an alphanumeric code, which may be roughly 10 bytes plus separator.

(8) Cookie Data Checksum – a long integer: 4 bytes.

5 The example cookie described above has about 68 bytes plus 10 separators. The separator character should be chosen so that the string does not have to be “escaped”; the caret (^) is frequently used this way. Thus, the typical size for the value string may be about 80 bytes.

10 FIG. 12 is an example of a color image 184 transmitted to a client 14a-14n in a system as shown in FIGS. 1 and 2. As shown in FIG. 12, the image 184 may be presented on a screen 182 on a display device associated with a client 14a-14n. A color image server 16a-16n associated with a particular subscriber 22a-22b, such as “ABC Company,” delivers image 184 to the client 14a-14n upon request. For purposes of illustration, image 184 may be accompanied by a legend 186 that identifies the
15 subscriber 22a-22n and a particular item being displayed. Also, an icon, button, or the like may accompany image 184 and indicate whether color correction has been applied by color image server 16a-16n, as indicated by reference numeral 188. In the example of FIG. 12, color correction has not been applied, e.g., because a subscriber cookie has not yet been generated for the particular subscriber 22a-22n. Another icon, button, or
20 the like may be displayed to invite the user to profile its display device, as indicated by reference numeral 190.

Elements 188 and 190 could be integrated with one another, as discussed previously, and take on an appearance such as a particular color scheme that indicates whether color correction has been applied. In either case, element 190 provides a
25 hypertext link to the URL associated with color profile server 18. Thus, when the user clicks on element 190, pages are requested from color profile server 18 for initiation of the color profiling process. If a profiler cookie already exists, however, it is sent by client 14a-14n to color profile server 18. In that case, there is no need to repeat the color profiling process. Instead, color profile server 18 creates a subscriber cookie for
30 the pertinent subscriber 22a-22n, and forwards it to the associated color image server

16a-16n, either directly without user intervention or indirectly with user approval as previously described.

FIG. 13 is block diagram illustrating transmission of color correction information in a system as shown in FIGS. 1 and 2. In particular, FIG. 13 illustrates a situation in which subscriber cookies have already been created for color image servers 194, 198 associated with particular subscribers 22a-22n accessed by an individual client 196. In this case, upon accessing a web page from a subscriber server 12a-12n, client 196 requests images from color image server 194. When requesting images from another subscriber 22a-22n, client 196 requests images from color image server 198. Color image server 194 incorporates both a color correction module 200 and an archive 202 of color images. Similarly, color image server 198 includes a color correction module 204 and an archive of color images 206.

When client 196 sends an image request to color image server 194, it sends along a color profile cookie, i.e., a subscriber cookie, as indicated by line 208. Likewise, as indicated by line 210, client 196 sends a subscriber cookie to color image server 198 when requesting an image. In each case, the subscriber cookie contains a color profile that provides color correction information for use by the respective color correction module 200, 204 in modifying, i.e., color correcting, the color images served from image archives 202, 206, respectively. Thus, when a request is received, color images server 194 or 198 processes the accompanying subscriber cookie to extract the contents, and controls the color correction module 200, 204 based on the extracted contents. In this manner, client 196 receives color corrected images, as indicated by reference numerals 212 and 214.

The manner in which color correction modules make use of the color profiles contained in the subscriber cookies will now be described. The foregoing discussion associated with FIGS. 4-11 above has utilized simplified one dimensional formulas to explain the relevance of blackpoint, average gamma, and adjusted gammas for RGB to account for gray balance. In the embodiment described with reference to FIGS. 4-11, blackpoints for each color channel are estimated based on red, green, and blue elements selected by a user associated with a respective client 14a-14n. Thus, the output of the color profiling process is a blackpoint RGB value and a gamma, or individual RGB

gammas. Now we assume that these values have been determined in the manner described above. The complete description of the display device behavior can be given by the following equation which relates RGB \rightarrow XYZ:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_{r,\max} & X_{g,\max} & X_{b,\max} \\ Y_{r,\max} & Y_{g,\max} & Y_{b,\max} \\ Z_{r,\max} & Z_{g,\max} & Z_{b,\max} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

where

$$R = \begin{cases} [(d_r - k_{o,r}) / (1.0 - k_{o,r})]^{\gamma_r} & [(d_r - k_{o,r}) / (1.0 - k_{o,r})] \geq 0 \\ 0 & [(d_r - k_{o,r}) / (1.0 - k_{o,r})] < 0 \end{cases}$$

$$G = \begin{cases} [(d_g - k_{o,g}) / (1.0 - k_{o,g})]^{\gamma_g} & [(d_g - k_{o,g}) / (1.0 - k_{o,g})] \geq 0 \\ 0 & [(d_g - k_{o,g}) / (1.0 - k_{o,g})] < 0 \end{cases}$$

$$B = \begin{cases} [(d_b - k_{o,b}) / (1.0 - k_{o,b})]^{\gamma_b} & [(d_b - k_{o,b}) / (1.0 - k_{o,b})] \geq 0 \\ 0 & [(d_b - k_{o,b}) / (1.0 - k_{o,b})] < 0 \end{cases}$$

The variables d_r , d_g , and d_b are the digital input values normalized to 1.0. The parameters $k_{o,r}$, $k_{o,g}$, and $k_{o,b}$ are the blackpoint offsets for the red, green, and blue channels, and the parameters γ_r , γ_g , and γ_b are the gammas for the red, green, blue channels. Thus, the gamma and blackpoint information contained in the subscriber cookie for a respective display device can be used in the above equations to produce, in effect, a destination device profile. The destination device profile, with a source profile previously computed for the requested image, can be used to perform a transformation of the image data sufficient to produce calibrated output on the display device.

The above approach is different than other attempts to characterize display devices such as equation 21 in Berns, "CRT Colorimetry. Part I: Theory and Practice."

In most characterizations, the "k" parameters are used to describe black offset rather

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<http://SubscriberName.com/images/ImageName.jpg>

could be replaced with:

<http://correction.SubscriberName.com/images/ImageName.jpg>.

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All images stored on the subscriber server 12a-12n may have a corresponding copy file of the same name residing on the subscriber color image server 16a-16n. The color image server 16a-16n may access this database of image files to read, convert, and send images referenced by the HTML page sent to the client 14a-14n. According to one embodiment, color image server 16a-16n may use a very simple and quick technique for color management. In particular, all images on the color image server 16a-16n preferably have a predetermined RGB color space. This typically means that original images are converted from the color space of corresponding source devices, e.g., such as scanners, digital cameras, and the like, to the standard color space determined by the subscriber 22a-22n. Good examples of standard RGB color spaces are ColorMatch RGB, which has a color temperature for the "virtual display" of D50. Other color spaces such as Adobe RGB have an excellent gamut, but have a color temperature of D65. When an image on an HTML page sent to the client 14a-14n is referenced via the color image server 16a-16n associated with a subscriber server 12a-12n such as:

correction.SubscriberName.com/images/ImageName.jpg

color image server 16a-16n accesses the corresponding image and converts the RGB data in real time before sending the image to the client destination. The conversion can be performed according to the following calculation:

$$R_s = \begin{cases} [(d_{r,s} - k_{o,r,s}) / (1.0 - k_{o,r,s})]^{r,s} & [(d_{r,s} - k_{o,r,s}) / (1.0 - k_{o,r,s})] \geq 0 \\ 0 & [(d_{r,s} - k_{o,r,s}) / (1.0 - k_{o,r,s})] < 0 \end{cases}$$

$$G_s = \begin{cases} [(d_{g,s} - k_{o,g,s}) / (1.0 - k_{o,g,s})]^{g,s} & [(d_{g,s} - k_{o,g,s}) / (1.0 - k_{o,g,s})] \geq 0 \\ 0 & [(d_{g,s} - k_{o,g,s}) / (1.0 - k_{o,g,s})] < 0 \end{cases}$$

$$B_s = \begin{cases} [(d_{b,s} - k_{o,b,s}) / (1.0 - k_{o,b,s})]^{b,s} & [(d_{b,s} - k_{o,b,s}) / (1.0 - k_{o,b,s})] \geq 0 \\ 0 & [(d_{b,s} - k_{o,b,s}) / (1.0 - k_{o,b,s})] < 0 \end{cases}$$

$$\begin{bmatrix} R_c \\ G_c \\ B_c \end{bmatrix} = \begin{bmatrix} X_{r,c,\max} & X_{g,c,\max} & X_{b,c,\max} \\ Y_{r,c,\max} & Y_{g,c,\max} & Y_{b,c,\max} \\ Z_{r,c,\max} & Z_{g,c,\max} & Z_{b,c,\max} \end{bmatrix}^{-1} \begin{bmatrix} X_{r,s,\max} & X_{g,s,\max} & X_{b,s,\max} \\ Y_{r,s,\max} & Y_{g,s,\max} & Y_{b,s,\max} \\ Z_{r,s,\max} & Z_{g,s,\max} & Z_{b,s,\max} \end{bmatrix} \begin{bmatrix} R_s \\ G_s \\ B_s \end{bmatrix}$$

$$d_{r,c} = k_{o,r,c} + (1.0 - k_{o,r,c}) \min(1.0, R_c)^{1/\gamma_{r,c}}$$

$$d_{g,c} = k_{o,g,c} + (1.0 - k_{o,g,c}) \min(1.0, G_c)^{1/\gamma_{g,c}}$$

$$d_{b,c} = k_{o,b,c} + (1.0 - k_{o,b,c}) \min(1.0, B_c)^{1/\gamma_{b,c}}$$

Note that the matrices above can be concatenated into a single matrix for increased processing speed.

FIG. 14 is a block diagram illustrating an alternative architecture for a system 214 for improving color image display accuracy in a computer network. System 214 conforms substantially to the system shown in FIG. 2, except that all images for the subscribers are stored at a central color image server 16. Color profiling server 18 may reside or be integrated with color image server 16 in the embodiment of FIG. 14. In this case, color profiling server 18 provides web pages for guidance of a color profiling process as described herein. Color image server 16 or color profile server 18 may include a database server for storage of individual color profiles associated with clients 14a-14n. When a client 14a-14n requests an image tagged in the code sent by one of subscriber servers 12a-12n, it is directed to the central color image server 16. The color image server 16 may use a client ID sent from the client to retrieve the appropriate color profile and apply it to modify the requested color image using techniques as described herein for color correction. In this manner, color image server 16 provides color corrected images without the need for transfer of cookies and the like between clients 14a-14n and the color image server.

A number of embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.